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Ground Vibration Induced by Moving Vehicle on Soft Soil

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***Abstract**: This research was conducted to gain more knowledge and investigate the ground vibration induced by vehicle at five different bridge approach location in Batu Pahat, Johor. This research also to illustrate and specify the ground vibration value based on identifying the location of an influence class of vehicle, speed of vehicle and zone of vehicle on bridge approach which are passing through to the bridge approach A (BAA) and bridge approach B (BAB). In describing vibration in the ground and in structures, the motion of the particle is utilized. This research describes the concepts of particle displacement, velocity and acceleration that are used to depict how the ground or structure reacts to excitation. This research observed the ground vibration motion, that is commonly described by identifying the peak particle velocity (PPV). Also presented, a description of the measurement technique, procedures and field data collection. From the sight of view of the result of this research, it indicated that the vibration value is more significant by all the variables. As a result, by the comparison of the variables that had been conducted with respect to the value of this vibration, it was found that the zone near the sensor shows a higher PPV value compared to the zone that is far apart from the sensor location and also vehicle class also plays a role which class IV is higher than class III and class II. The research shows potential to provide and improve the knowledge towards the importance of ground vibration from the vehicle loading by specific evaluation.*

***Keywords**: Bridge approach, ground vibration, vehicle loading, peak particle velocity.*

I. INTRODUCTION

In this age, due to the growing need for regional development, an engineer faces a challenge to discover a secure method to build transport infrastructure on soft soils [1, 2, 3, 4]. The settlement of soft soil foundation has clad to be amongst one of the tough circumstances to be noticed for foundation design with the rapid growth of infrastructure and building construction. With regards to geotechnical characteristics, soft soil is well known for its low bearing capacity, high water content, high differential settlement, long term settlement and can not withstand external loads without having significant deformation [1, 2, 3, 5]. While, a surcharge or an increase in pressure, including strain or settlement, comes when an infrastructure such as road embankment and bridge approach is constructed over soft soil. In case the additional surcharge load due to filling and construction is over the top close the ultimate bearing capacity of the supporting soft ground in the vertical and lateral direction, immoderate yield or plastic deformation may occur followed through tension crack, deep seated rotational slip when massive and significance deformation occurs. The settlement at the end of a bridge near the connection between the abutment and the embankment is a constant problem for road organizations [1, 6, 7]. There are several explanations why bridge approach settlement was previously examined by other researchers before and one of the issues is a disparity between the height of the bridge and road on the connection. A study of previous research revealed various potential causes of bridge approach distress and that the settlement of the bridge approach is primarily a site specific problem [7, 8, 9, 10, 11, 12, 13, 14].

Maintenance operations and traffic on the road can also be a cause of vibration. If its amplitudes are high enough, ground vibration may potentially damage the structures and cause cosmetic damage. According to [15], the movement of particle is used to explain motion in the ground and structures. The concepts of particle displacement, velocity and acceleration are used to demonstrate how the soil or structure responds to excitement. [15] also mentioned, while displacement is usually easier to understand than velocity or acceleration, it is seldom used to explain motion on the ground and structure, considering that most transducers used to calculate vibration explicitly measure velocity or acceleration, not displacement. By defining the peak particle velocity (PPV), vibratory motion is commonly described by appropriate and Fig. 1 demonstrated described zero-to-peak amplitude.

Displacement is typically measured in inches (in.) or millimeters (mm). Velocity is measured in inches per second (in/Sec) or millimeters per second (mm/Sec). Acceleration is measured in in/Sec per second (in/Sec^2), mm/Sec per second (mm/Sec^2), or relative to the acceleration of gravity (g) (32.2 feet [ft.] /Sec^2 or 9.8 meters [m] /Sec^2).

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A disruption propagates away from the source of vibration at the point when the ground is reliant on vibratory excitation from a vibratory source. The ground is demonstrated as an infinite elastic half space to test ground vibration propagation over distance. The body of this type of medium can sustain two types of waves which is “compression” or “primary” waves (P-waves), and “secondary” or “shear” waves (S-waves) as knows as “body waves”. The particle motion related to a P-wave is a push-pull motion parallel to the direction of the wave front, while particle motion associated with an S wave is a transverse displacement normal to the direction of the wave front [15].

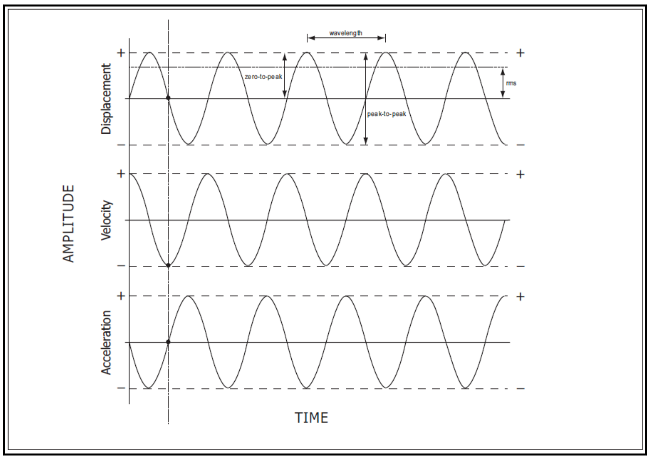

Fig. 1: Quantities used to describe vibratory motion [15]

The objective of this research is to define and develop methods of field investigation to examine the impact of vibration from vehicle loading at bridge approaches and this situation could be known as a repetitive cyclic loading. The aim of this research is to investigate the impact and effect of vehicle loading at bridge approaches on settlement. For the bridge approach, a higher level of vibration may not be appropriate and may impact such as surface cracking, bumpy condition, pothole and differential settlement. In this analysis, researchers concentrate on the effects of vehicle loading vibration due to the effect of the settlement on a bridge approach.

According to [16, 17, 18, 19, 20], for field surveillance or laboratory testing, researchers often choose to use the Piezoelectric (ICP) accelerometer. Measuring equipment with a portable vibration measuring system with high sensitivity triaxial ICP accelerometer used to investigate the impact of vehicle loading vibration at bridge approaches at a certain distance set at the beginning of the investigation. A seismic wave travel causing soil and rock particles to move back and forth over very small distances as vibration occurs in a source is known as particle velocity. The peak particle velocity (PPV) is defined as the motion of each particle at a maximum velocity and as the standard for measuring the intensity of the ground vibration. The PPV is commonly used for ground vibration surveillance [16, 21, 22]. According to [16, 23, 24], the PPV is also the standard measurement tool for monitoring and prevention of disasters that is usually used in the construction of vibration management or vibration emissions due to transport in several recent regulations and guidelines. Overall, the vibration monitor study proves helpful in demonstrating whether vibration is sufficiently large to trigger bridge approach concerns and the amplitude of the vibration additionally can be used with the guidelines for vibration control [16, 25]. The ground vibration is calculated in term PPV, which refers to the sum of the vector at the peak vibration element [16, 26, 27].

II. MATERIAL AND METHODS

A. Study Area

The field test was conducted on soft soil area in Batu Pahat, Johor. This location is well known a soft soil area based on some of problematic areas in Malaysia that deals with soft soil that are challenging for the construction of a bridge, building and infrastructure. Site description and observation had conducted to identify the actual situation and as a guide for further planning in this study. The field test location is shown in Fig. 2 as follow:

a) Bridge Km 0.4, Jln Parit Karjo (J209)
b) Bridge Km 6.2, Jln Parit Karjo (J209)
c) Bridge Km 2.5, Jln Sengkuang Seri Bengkal-Parit Yaani (J125)
d) Bridge Km 11.6, Jln Seri Bengkal-Parit Yaani (J125)
e) Bridge Sg. Simpang Kiri, Kg. Kangkar Merlimau

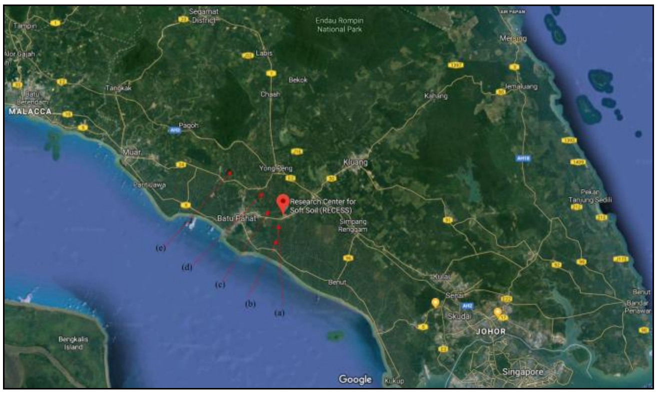

Fig. 2: Site location of field testing at Batu Pahat, Johor

B. Method of Testing

This research starts with preliminary study, which is important to find the right method for collecting relevant data. The approach used in this research is to determine the vehicle’s vibration value through the road and bridge that is measured depending on the vehicle class, speed and area zone passed by the vehicle using a sensor called a triaxial ICP accelerometer. The DEWE Soft X3 computer software used to monitor, process, record and store information data of the ground vibration. With this software’s single integration feature, the transformation of raw acceleration data to x-axis, y-axis, z-axis and also PPV data is performed in real time. The velocity of propagation is the speed that wave travels through the cork, while the particle velocity is the velocity that moves up and down with the cork. With a solid and dense material, a wave propagates faster than with a soft and flexible material.

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At the initial stage, the research's location will be diversified in order to see and monitor whether there is a distinction or similarity between the locations involved, while at the same time improving the ability to use resources and ways to deal with problems that exist in the tools. In the time-domain, the vibration data were measured using the particle velocity (mm/s) as the main unit for the amplitude of the vibration. In research, there are three main components that have been integrated together to measure vibration from the ground surface as shown in Fig. 3, namely; triaxial ICP accelerometer sensor, data acquisition module, and portable computer.

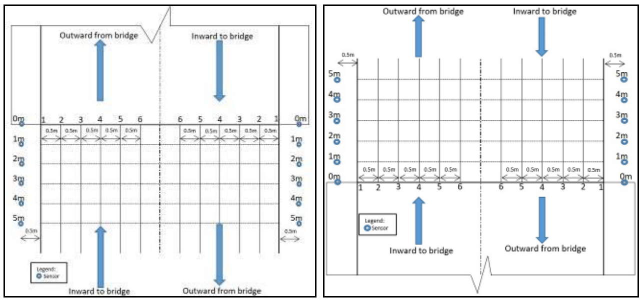
Fig. 3: Measuring equipment;
(a) Data acquisition module 4 channel ;
b) triaxial ICP accelerometer ; (c) 4 pin BNC cable

High sensitivity triaxial ICP accelerometer measures the vibration in three dimensions such as x-axis, y-axis and z-axis, resulting more accurate peak particle velocity by combining all three directions of the vibration amplitude. In preparation of vibration monitoring test, high sensitivity triaxial ICP accelerometer mounted together with the steel base plate before the peg in the ground to be more stable. Then, the connecting cable which has a length of 10m, directly connected to portable vibration measurement system device and by using Universal Serial Bus (USB) powered connected to a laptop as shown in Fig 4.

Fig. 4: Measuring equipment arrangement;
(a) Data acquisition module 4 channel; (b) Portable computer; (c) Triaxial ICP accelerometer

The data obtained by using the DEWESoft X3 software that provided together with the data acquisition device were processed and recorded real time with sampling rate 5000Hz of the triaxial ICP accelerometer. The software also used for post processing data. The software capable of recording velocity in mm/s, directly by translating the voltage input from the connected sensor in time domain. The software then performed real time mathematical equation, especially integration and double integration of the acceleration data, resulting other two vibration amplitude which is acceleration in m/s^2 and displacement in mm. Once the equipment is provided, preferably, the test can be done to obtain the data that is best for analysis.

Accordingly, careful planning needs to be done before the field test that will conduct to obtain the best data. Fig. 5 shows the zone setting for vehicle data through the bridge approach area at the study location in the bridge approach A (BAA) and bridge approach B (BAB).



(a) BAA **(b) (BAB)**

Fig. 5: Zone of measuring vibration at bridge approach

The bridge approach measured and marked at a distance of 0.5m interval which is shown in Fig.6. The observed data are based on three variables that are speed of vehicle, vehicle class, and vehicle travel zone. The goal is to obtain the vibration amplitude of the vehicle which passes through the designated zones. It is based on Class I, II, III and IV as shown in Table I for the observation of different types and size of the vehicle.

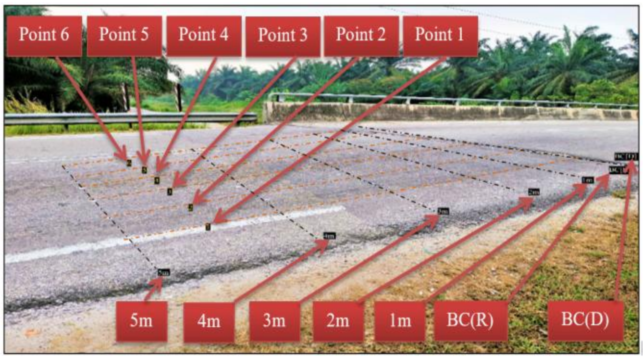


Fig. 6: Bridge approach marked prior to Fig.5

Table-I: Classification of vehicles

Vehicle Class	Type of Vehicle
Class I	Motorcycles
Class II	Cars
Class III	SUV, Van, MPV, Small lorries (6 tones and less)
Class IV	Bus, Big lorries (more than 6 tones)

III. RESULT AND DISCUSSION

A. Zone travelled by the vehicle

By referring to Table 2, the data obtained in BAA and BAB found the similarity of vehicle percentage through zone 2 and zone 3 is more than zone 1 and zone 4. Therefore, this zone 2 and zone 3 should give more attention in subsequent analyses based on the frequency of vehicles passing through.

Table-II: Percentage (%) vehicles passing by zone

Site	BAA				BAB			
	Zone				Zone			
	1	2	3	4	1	2	3	4
A	17.8	52.2	23.3	6.7	15.2	43.5	37.0	4.3
B	13.3	47.8	32.2	6.7	9.5	52.6	32.6	5.3
C	16.8	47.4	32.6	3.2	13.3	47.8	36.7	2.2

D	18.4	46.1	30.3	5.3	11.1	51.1	35.6	2.2
E	3.4	34.5	58.6	3.4	7.8	53.2	36.4	2.6

B. PPV value of field measurement

Based on data analysis in all study areas, it is possible to determine the value of PPV based on the type of vehicle, the position of the sensor and the zone through which the vehicle is traveling. The data obtained in both bridge approaches are BAA and BAB. Table 3 shows the PPV range covering all study sites. It is found that, at the position of the sensors 0m with a bridge connection at bridge deck (BC [D]), bridge connection at roadway (BC [R]) and 1m, the PPV value is higher than the sensor position at 2m, 3m, 4m and 5m. This gives the impression that higher vibration value is 1m away from the bridge connection. Given this value, further studies will focus on the area in more detail.

Table-III: Range of PPV value of vehicles at site location

Site	Location	Sensor Point	PPV (mm/s)	
			BAA	BAB
A	Bridge Km 0.4, Jln Pt Karjo (J209)	BC[D]	9.39 – 154.59	4.53 – 80.06
		BC[R]	0.54 – 58.00	0.19 – 4.36
		1m	0.27 – 14.17	0.16 – 2.03
		2m	0.19 – 8.06	0.15 – 1.73
		3m	0.19 – 7.40	0.12 – 1.64
		4m	0.16 – 4.40	0.13 – 1.54
		5m	0.11 – 3.59	0.11 – 1.25
B	Bridge Km 6.2, Jln Pt Karjo (J209)	BC[D]	7.98 – 92.75	3.62 – 46.43
		BC[R]	0.45 – 34.22	0.15 – 2.49
		1m	0.23 – 8.22	0.12 – 1.18
		2m	0.16 – 4.67	0.12 – 1.02
		3m	0.16 – 4.22	0.09 – 0.98
		4m	0.13 – 2.46	0.10 – 0.85
		5m	0.09 – 1.80	0.09 – 0.74
C	Bridge Km 2.5, Jln Sengkuang Seri Bengkal - Pt Yaani (J125)	BC[D]	6.57 – 78.84	3.17 – 48.84
		BC[R]	0.37 – 29.58	0.13 – 2.70
		1m	0.19 – 6.94	0.11 – 1.28
		2m	0.13 – 3.87	0.10 – 1.11
		3m	0.13 – 3.48	0.08 – 1.07
		4m	0.11 – 2.07	0.08 – 0.99
		5m	0.08 – 1.65	0.07 – 0.83
D	Bridge Km 11.6, Jln Seri Bengkal - Parit Yaani (J125)	BC[D]	4.23 – 54.11	2.31 – 44.03
		BC[R]	0.24 – 19.22	0.10 – 2.35
		1m	0.12 – 4.96	0.09 – 1.14
		2m	0.07 – 2.90	0.08 – 0.99
		3m	0.08 – 2.44	0.06 – 0.97
		4m	0.07 – 1.41	0.06 – 0.89
		5m	0.05 – 1.26	0.05 – 0.76
E	Bridge Sg. Simpang Kiri, Kg. Kangkar Merlimau	BC[D]	7.04 – 108.21	3.44 – 55.24
		BC[R]	0.40 – 40.02	0.15 – 2.96
		1m	0.20 – 9.21	0.13 – 1.36
		2m	0.14 – 4.84	0.11 – 1.19
		3m	0.14 – 4.96	0.09 – 1.15
		4m	0.12 – 3.04	0.10 – 1.00
		5m	0.08 – 2.37	0.08 – 0.84

Fig. 7 shows, the sample of PPV value obtain from the field testing by Class IV vehicle at BC[D].

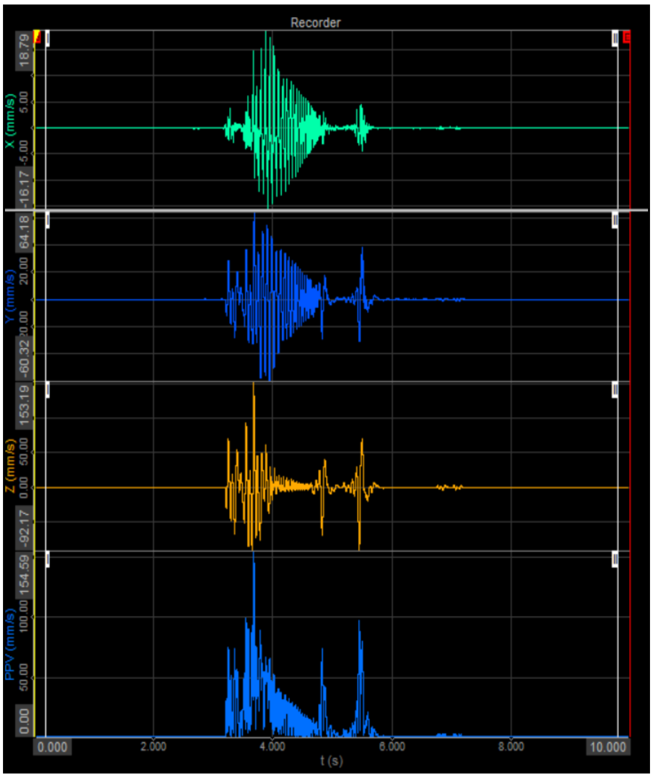


Fig. 7: PPV value of Class IV vehicle at BC[D]

C. Influence by vehicle class, sensor location and zone

Fig. 8 and Fig. 9 shows the value of PPV based on the sensor location and vehicle class II at zone 2 and zone 3 at BAA and BAB. It shows a significant difference between the value of PPV at sensor location BC [D], BC [R] and 1m. Then, the value of PPV at sensor location 2m, 3m, 4m and 5m decreases with uniform rates. In this regard, it can be expressed here that the critical area is in the 1m area before a bridge connection. For the comparison values between zones, zone 2 showed higher readings of vibration values compared to zone 3 for all study locations.

The PPV value range of class II vehicles for all study sites at BAA is 9.47mm/s – 23.31mm/s at BC [D], then 0.69mm/s – 2.57mm/s at BC [R], at 1m (0.23mm/s – 0.51mm/s), at 2m (0.21mm/s – 0.46mm/s), at 3m (0.15mm/s – 0.27mm/s), 4m (0.13mm/s – 0.41mm/s), and at 5m (0.08mm/s – 0.18mm/s). Then, at BAB the value of the PPV is dramatically decreased because of the observation vehicle speed, when the vehicle is almost through the BAA the speed of the vehicle decreases slightly from the original speed and when passing through the next bridge to the vehicle speed limit. When after the vehicle had passed the BAB within 5m above the speed of the vehicle has increased. In previous studies it was stated that the speed of the vehicle also affects the vibration value which is the PPV value directly proportional to the speed of the vehicle. Furthermore, the PPV value range of class II vehicles for all study sites at BAB is 0.15mm/s – 0.45mm/s at BC [D], then 0.15mm/s – 0.35mm/s at BC [D], at 1m (0.14mm/s – 0.29mm/s), at 2m (0.12mm/s – 0.27mm/s), at 3m (0.10mm/s – 0.23mm/s), 4m (0.07mm/s – 0.19mm/s), and at 5m (0.07mm/s – 0.13mm/s).

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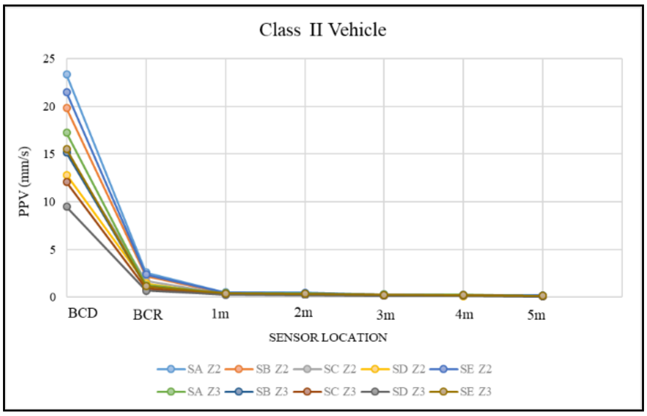

Fig. 8: PPV value of Class II vehicle at BAA

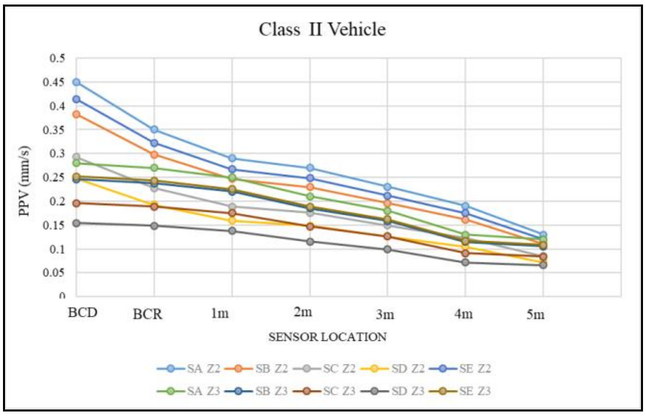

Fig. 9: PPV value of Class II vehicle at BAB

Fig. 10 and Fig. 11 shows the value of PPV value for vehicle class III at zone 2 and zone 3 at BAA and BAB based on the sensor location. From the observation, it also shows a significant difference between the value of PPV at sensor location BC[D], BC[R] and 1m. Compared to class II, there was a significant increase in PPV value of class III vehicles that have been recorded when the maximum PPV value of class III vehicles for all study sites at BAA is 68.4mm/s at BC[D], 3.33mm/s at BC[R], at 1m (1.78mm/s), at 2m (1.12mm/s), at 3m (0.88mm/s), 4m (0.89mm/s), and at 5m (0.60mm/s). Meanwhile, the maximum PPV value of class III vehicles for all study sites at BAB is 1.84mm/s at BC [D], 1.25mm/s at BC [R], at 1m (1.16mm/s), at 2m (0.93mm/s), at 3m (0.88mm/s), 4m (0.79mm/s), and at 5m (0.58mm/s).

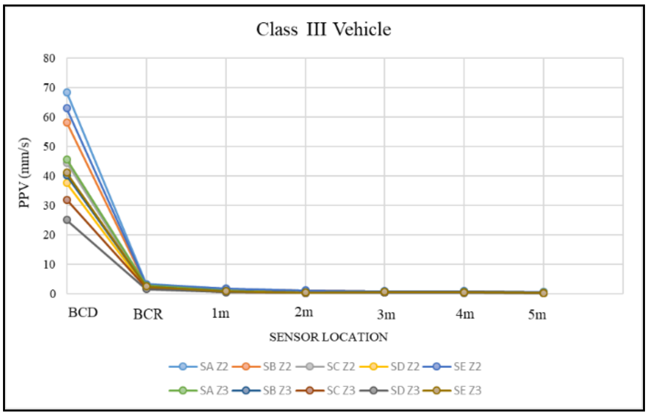

Fig. 10: PPV value of Class III vehicle at BAA

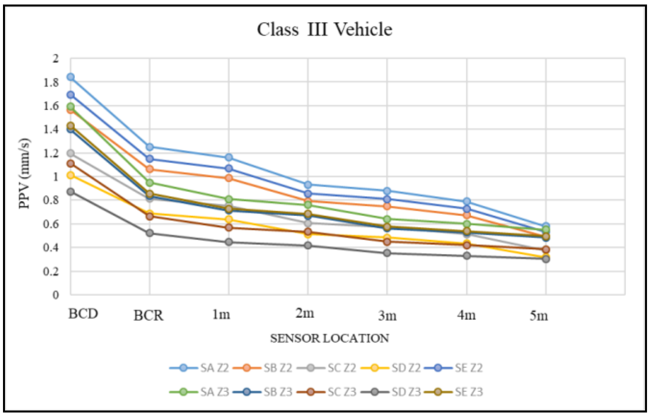

Fig. 11: PPV value of Class III vehicle at BAB

Fig. 12 and Fig. 13 shows the value of PPV based on the sensor location and vehicle class IV at zone 2 and zone 3 at BAA and BAB. For comparison, the value of PPV for class IV vehicles at all study sites, there are significant differences compared to class II and not significantly different from class III. The conclusion can be stated here that, with high PPV values by these class IV vehicles, it will have more impact than the class II and III vehicles. Furthermore, as a review of the vehicle route zone, in all of the analyzes conducted, it was found that at the beginning of this study of the position of BC [D], BC [R] and 1m had a higher impact on PPV value compared to position other sensors.

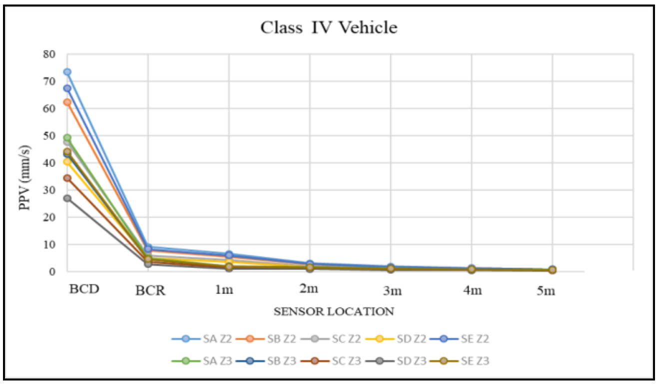

Fig. 12: PPV value of Class IV vehicle at BAA

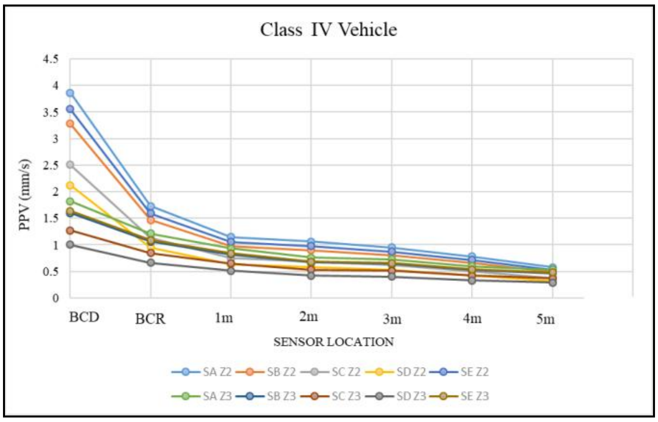

Fig. 13: PPV value of Class IV vehicle at BAB

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IV. CONSLUCIONS

In conclusion, from the visual observation, all sites experience the same situation where there is a settlement between the bridge and the road. Studies on the effects of vibration on the settlement will be carried out to ensure that this study is relevant and has a future impact. By analyzing across all study sites, Site A showed higher vibration values compared to other sites. According to a set of high value, PPV for study areas starting from Site A, Site E, Site B, Site C and Site D. By the analysis carried out through the measurement of the vibration value at the site location, found that the three variables play their respective roles. Then, by comparison of the variables that had been conducted with respect to the value of this vibration, it was found that the zone near the sensor shows a higher PPV value compared to the zone that is far apart from the sensor location and also vehicle class also plays a role which class IV is higher than class III and class II. The advantages of this study to provide and improve the knowledge towards the importance of the vehicle loading of the bridge approach by specific observation and evaluation.

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